

# ACYCLIC ANIONIC SIX-ELECTRON-DONOR ANCILLARY LIGANDS

## BACKGROUND OF THE INVENTION

### 1. Field of the Invention

This invention relates to transition metal complexes with ancillary ligands, and in particular, to acyclic anionic six-electron donor ancillary ligands.

### 2. Background Art

The chemical industry uses a wide variety of transition metal complexes as catalysts for organic reactions. Olefin polymerization is an important example of such a reaction. While conventional Ziegler-Natta catalysts continue to dominate the industry, highly active metallocene or single-site catalysts which provide polymers with properties such as narrow molecular weight distributions, low densities, and good co-monomer incorporation, are emerging.

Transition metal complexes used to polymerize olefins are normally non-zero-valent metals (e.g.,  $Ti^{4+}$ ,  $Zr^{4+}$ ,  $Sc^{3+}$ ) surrounded by anionic ligands (e.g., chloride, alkyl, cyclopentadienyl) that satisfy the valency of the metal. The nature of the various anionic ligands can dramatically affect catalyst activity and polymer properties. Thus, by varying the choice of anionic ligand, a catalyst structure can be fine-tuned to produce polymers with desirable properties. Furthermore, the anionic ligand will affect the stability of the transition metal complexes.

Metallocene polymerization catalysts contain one or two cyclopentadienyl groups as anionic ligands. These serve to stabilize the active catalytic species, modulate the electronic and steric environment around the active metal center, and maintain the single-site nature of the catalyst. Polymers with narrow molecular weight and composition distributions may be produced using these metallocene catalysts. Such complexes frequently contain substituted cyclopentadienyl groups. By utilizing substituted cyclopentadienyl moieties, the

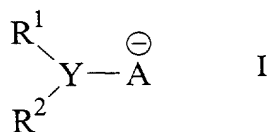
geometry and electronic character of the active site may be altered, thus altering the activity and stability of the catalyst as well as the properties of the polyolefins produced therefrom.

Further anionic ligands are those which are heteroatomic ring ligands isolobal to the cyclopentadienyl ring; that is, the orbital interaction of the metal with the ligand is similar in both cases. Examples of such ligands are boraaryl (see, e.g., U.S. Pat. No. 5,554,775), pyrrolyl and indolyl anions (U.S. Pat. No. 5,539,124), azaborolinyl groups (U.S. Pat. No. 5,902,866), phospholyl anions, and tris(pyrazolyl)borate anions.

Transition metal complexes with highly delocalized cyclic anionic six-electron-donor ancillary ligands are important precursors for a variety of highly efficient catalysts. The performance and cost of these catalysts are strongly dependent on the structure of the ligands. It would be desirable to provide transition metal complex catalysts in addition to those presently available in order to provide further options with regard to catalytic activity and stability and polyolefin product properties.

### SUMMARY OF THE INVENTION

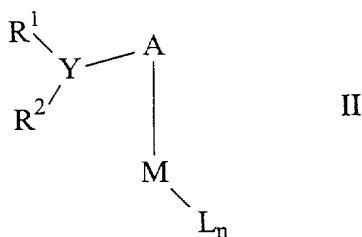
In one embodiment of the present invention, a delocalized anionic acyclic ligand capable of providing six electrons when coordinated to a transition metal is provided. The structure of the ligand of the present invention is given by:



where A is CH<sub>2</sub>, CHR<sup>3</sup>, CR<sup>3</sup>R<sup>4</sup>, NR<sup>3</sup>, O, S, or PR<sup>3</sup>; R<sup>1</sup> and R<sup>2</sup> are each independently hydrogen, an aryl group, preferably a C<sub>6-15</sub> aryl group, a C<sub>6-15</sub> arylphospho group (each aryl is C<sub>6-15</sub>), a C<sub>6-15</sub> arylthio group, C<sub>7-15</sub> alkyl group,

C<sub>1-10</sub> alkoxy group, C<sub>6-14</sub> aryloxy group, a C<sub>1-10</sub> dialkylamino group (each alkyl is C<sub>1-10</sub>), or a C<sub>6-15</sub> diarylamino group (each aryl is C<sub>6-15</sub>); R<sup>3</sup> and R<sup>4</sup> are each independently hydrogen, a C<sub>1-8</sub> alkyl group, C<sub>6-10</sub> aryl group, or C<sub>7-15</sub> aralkyl group; and Y is B, Al, or Ga. It should be noted that in compounds containing "C<sub>6-15</sub> diaryl" groups and similar designations, the C<sub>6-15</sub> refers to each aryl group rather than the total carbon content of the ligand.

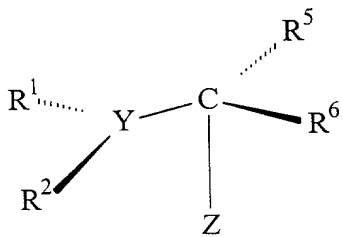
In another embodiment of the present invention, a transition metal complex incorporating the ligand of structure I is provided. The structure of the complex of the present invention is:



where M is a transition metal; L is a sigma bonded or pi bonded ligand; n is an integer such that the valency of M is satisfied; A is CH<sub>2</sub>, CHR<sup>3</sup>, CR<sup>3</sup>R<sup>4</sup>, NR<sup>3</sup>, O, S, and PR<sup>3</sup>; R<sup>1</sup> and R<sup>2</sup> are each independently hydrogen, C<sub>6-10</sub> aryl, diarylphospho, C<sub>1-18</sub> alkylthio, C<sub>6-15</sub> arylthio, C<sub>7-15</sub> aralkyl, C<sub>1-10</sub> alkoxy group, C<sub>6-14</sub> aryloxy group, C<sub>1-10</sub> dialkylamino group, or C<sub>6-15</sub> diarylamino group; R<sup>3</sup> and R<sup>4</sup> are each independently hydrogen, C<sub>1-8</sub> alkyl, C<sub>6-10</sub> aryl, C<sub>7-15</sub> aralkyl, C<sub>1-10</sub> alkoxy, C<sub>6-14</sub> aryloxy, C<sub>1-10</sub> dialkylamino, or C<sub>6-15</sub> diarylamino, and Y is B, Al, or Ga.

In still another embodiment of the present invention, a method for forming the metal complex having the ligand of the present invention is provided.

The method comprises reacting a ligand precursor having the following structure:



### III

where Z is a leaving group, with a metal compound with the structure:

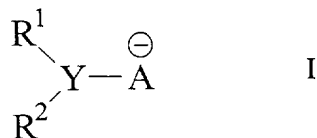


where X is a halogen, to form metal complex II. L and n are as defined above.

### 5 DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Reference will now be made in detail to presently preferred compositions or embodiments and methods of the invention, which constitute the best modes of practicing the invention presently known to the inventor. It should be noted that the term "six-electron-donor ancillary ligands" refers to ligands capable of bonding to a metal atom through six electrons.

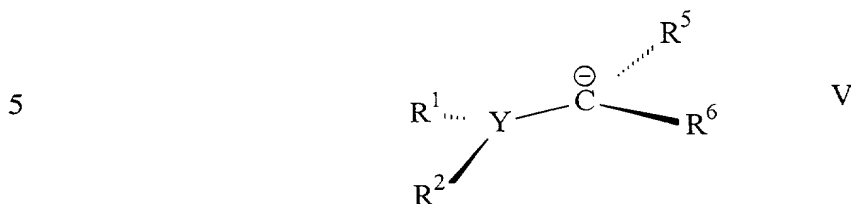
In one embodiment of the present invention, a delocalized anionic acyclic ligand capable of providing six electrons while coordinated to a transition metal is provided. The structure of the ligand of the present invention is given by:



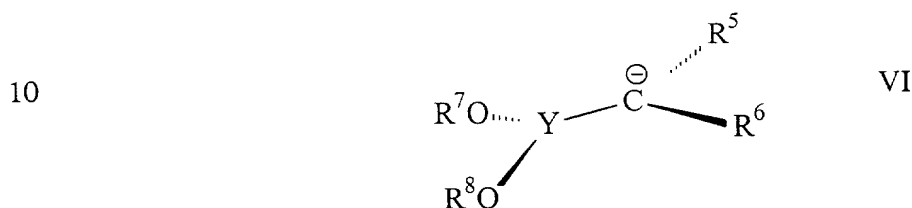
where A is CH<sub>2</sub>, CHR<sup>3</sup>, CR<sup>3</sup>R<sup>4</sup>, NR<sup>3</sup>, O, S, or PR<sup>3</sup>; R<sup>1</sup> and R<sup>2</sup> are each independently hydrogen, C<sub>6-10</sub> aryl, a C<sub>6-15</sub> diarylphospho group (each aryl is C<sub>6-15</sub>), a C<sub>1-18</sub> alkylthio group, a C<sub>6-15</sub> arylthio group, C<sub>7-15</sub> aralkyl group, C<sub>1-10</sub> alkoxy group, C<sub>6-14</sub> aryloxy group, a C<sub>1-10</sub> dialkylamino group (each alkyl is C<sub>1-10</sub>), or C<sub>6-15</sub> diarylamino group (each aryl is C<sub>6-15</sub>); R<sup>3</sup> and R<sup>4</sup> are each independently hydrogen,

a C<sub>1-8</sub> alkyl group, C<sub>6-10</sub> aryl group, or C<sub>7-15</sub> aralkyl group; and Y is B, Al, or Ga. Furthermore, R<sup>1</sup> and R<sup>2</sup> may optionally be bonded to form a cyclic structure.

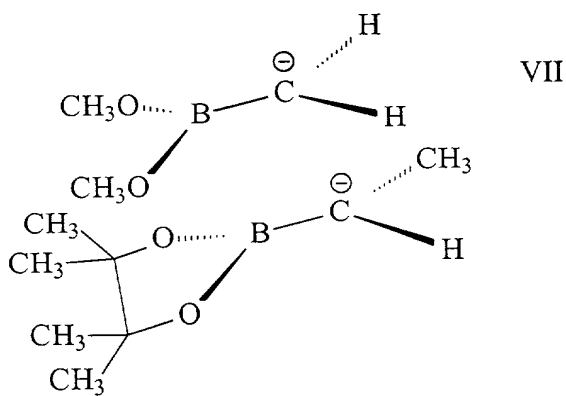
In a preferred embodiment of the present invention, the anionic ligand is given by the formula V:



where R<sup>1</sup> and R<sup>2</sup> are the same as above; R<sup>5</sup> and R<sup>6</sup> are independently hydrogen, a C<sub>1-8</sub> alkyl group, C<sub>6-10</sub> aryl group, C<sub>7-15</sub> aralkyl group, C<sub>1-10</sub> alkoxy group, C<sub>6-14</sub> aryloxy group, C<sub>1-10</sub> dialkylamino group, or C<sub>6-15</sub> diarylamino group. In a refinement of this embodiment a preferred ligand is given by formula VI:

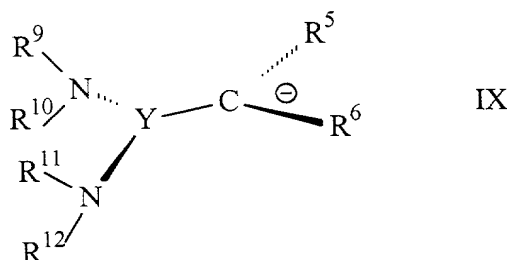


where R<sup>5</sup> and R<sup>6</sup> are the same as above; R<sup>7</sup> and R<sup>8</sup> are independently a C<sub>1-8</sub> alkyl group, C<sub>6-10</sub> aryl group, or C<sub>7-15</sub> aralkyl group. Examples of this refinement include but are not limited to compounds given by structures VII and VIII:



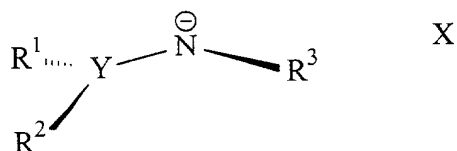
## VIII

In another refinement of the ligand of structure V, a preferred ligand is given by structure IX:

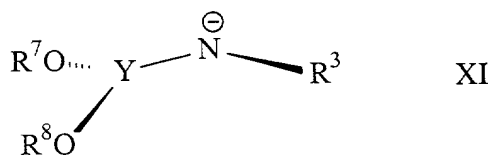


- 5 where  $R^5$  and  $R^6$  are the same as above and  $R^9$ ,  $R^{10}$ ,  $R^{11}$ , and  $R^{12}$  are independently a  $C_{1-8}$  alkyl group,  $C_{6-10}$  aryl group, or  $C_{7-15}$  aralkyl group.

Another preferred ligand is provided by the group illustrated by structure X:



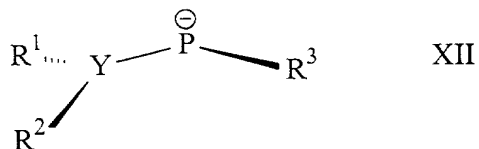
- 10 where Y,  $R^1$ ,  $R^2$ , and  $R^3$  are as provided above. In a variation of this preferred embodiment, the anionic ligand is described by structure XI:



where Y,  $R^3$ ,  $R^7$ , and  $R^8$  are as provided above.

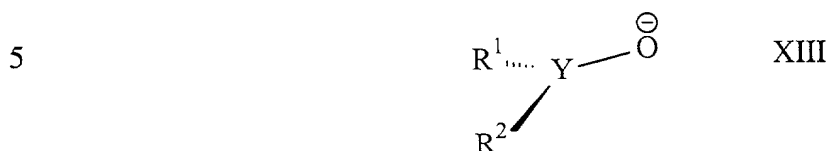
Another preferred ligand is provided by the group illustrated by structure XII:

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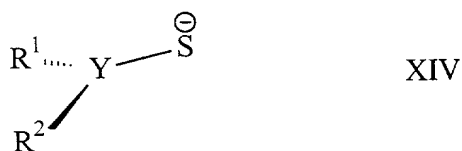
where Y, R<sup>1</sup>, R<sup>2</sup>, and R<sup>3</sup> are as provided above.

Another preferred ligand is provided by the group illustrated by structure XIII:



where Y, R<sup>1</sup>, and R<sup>2</sup> are as provided above.

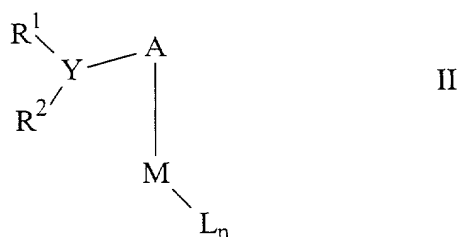
Another preferred ligand is provided by the group illustrated by structure XIV:



10 where Y, R<sup>1</sup>, and R<sup>2</sup> are as provided above.

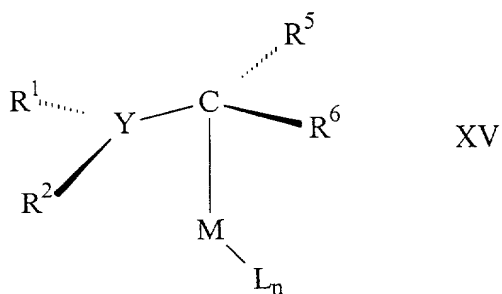
In another embodiment of the present invention, a transition metal complex incorporating the ligand of structure I is provided. The structure of the complex of the present invention is:



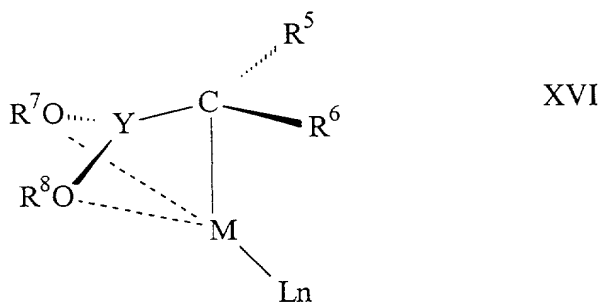


where M is a transition metal; L is a sigma bonded or pi bonded ligand; n is an integer such that the valency of M is satisfied; A is CH<sub>2</sub>, CHR<sup>3</sup>, CR<sup>3</sup>R<sup>4</sup>, NR<sup>3</sup>, O, S, and PR<sup>3</sup>; R<sup>1</sup> and R<sup>2</sup> are each independently hydrogen, a C<sub>6-15</sub> diarylphospho group, a C<sub>1-18</sub> alkylthio group, a C<sub>6-15</sub> arylthio group, C<sub>7-15</sub> aralkyl group, C<sub>1-10</sub> alkoxy group, C<sub>6-14</sub> aryloxy group, C<sub>1-10</sub> dialkylamino group, or C<sub>6-15</sub> diarylamino group; and Y is B, Al, or Ga. The transition metal M is preferably a Group 3 to 10 transition or lanthanide metal. Preferred Group 3 to 10 metals comprise Sc, Ti, Cr, Mn, Fe, Co, Ni, and elements directly below these in the Periodic Table. Preferred lanthanide metals include La, Ce, Pr, Eu, Yb, and the like. More preferably, the transition metal complex comprises a Group 3 to 6 transition or lanthanide metal, and most preferably, a Group 4 transition metal. The sigma bonded or pi bonded ligands, L, are preferably one or more anionic or neutral ligands. The one or more anionic or neutral ligands are present in an amount determined by n such that the valency of M is satisfied. Examples include unsubstituted and substituted cyclopentadienyl, indenyl, fluorenyl, hydride, halide, alkyl, aryl, aralkyl, dialkylamino, siloxy, alkoxy, pyrrolyl, indolyl, carbazoyl, quinolinyl, pyridinyl, azaborolinyl, boraaryl groups, or the like, and combinations of these. Examples of neutral ligands are carbonyl, η<sup>6</sup>-aryl, η<sup>4</sup>-butadiene, η<sup>4</sup>-cyclobutadiene, η<sup>4</sup>-cyclooctatetraene, tertiary phosphine, and the like. Other examples of suitable anionic or neutral ligands appear in U.S. Pat. Nos. 5,756,611, 5,637,659, 5,637,660, 5,554,775, and 5,539,124, the teachings of which are incorporated herein by reference.

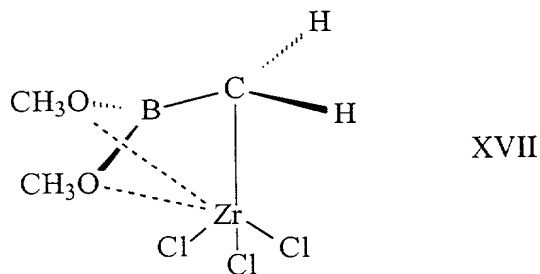
In a particularly preferred embodiment of the present invention, a transition metal complex having the anionic ligand of the present invention is provided by structure XV:

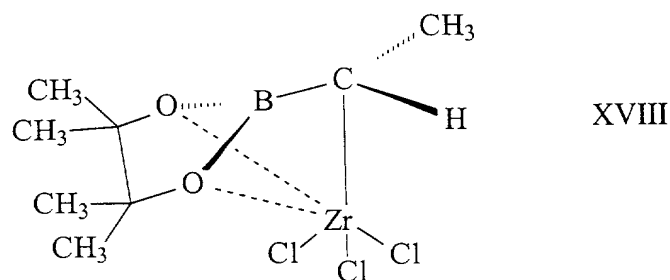


where  $R^1$  and  $R^2$  are as provided above;  $R^5$  and  $R^6$  are independently hydrogen, a  $C_{1-8}$  alkyl group,  $C_{6-10}$  aryl group,  $C_{7-15}$  aralkyl group,  $C_{1-10}$  alkoxy group,  $C_{6-14}$  aryloxy group,  $C_{1-10}$  dialkylamino group, or  $C_{6-15}$  diarylamino group. In a refinement of this embodiment a preferred ligand is given by formula XVI:

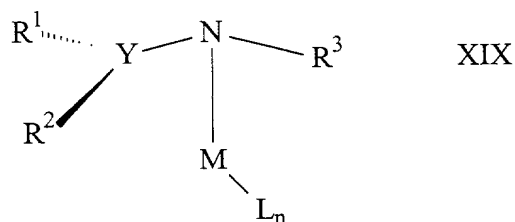


where  $R^5$  and  $R^6$  are as provided above;  $R^7$  and  $R^8$  are independently a  $C_{1-8}$  alkyl group,  $C_{6-10}$  aryl group, or  $C_{7-15}$  aralkyl group. Examples of this refinement include but are not limited to compounds given by structures XVII and XVIII:

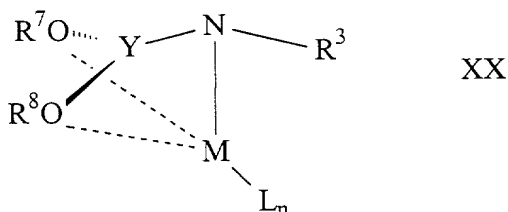




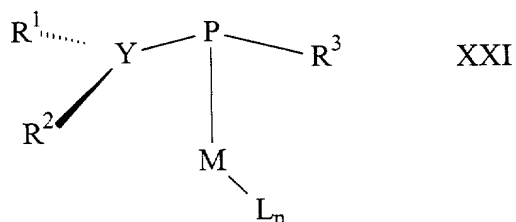
Another particularly preferred complex is provided in structure XIX:



- 5 where Y, R<sup>1</sup>, R<sup>2</sup>, and R<sup>3</sup> are as provided above. In a variation of this preferred embodiment, the anionic ligand is described by structure XX:

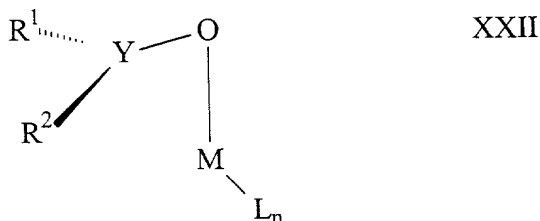


Still another preferred metal complex is provided by structure XXI:



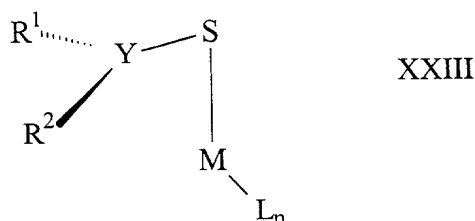
where Y, M, n, R<sup>1</sup>, R<sup>2</sup>, and R<sup>3</sup> are as provided above.

Still another preferred embodiment of the present invention, is provided by the complex provided in structure XXII:



5 where Y, M, n, R<sup>1</sup>, and R<sup>2</sup> are as provided above.

Still another preferred embodiment of the present invention, is provided by the complex provided in structure XXIII:



where Y, M, n, R<sup>1</sup>, and R<sup>2</sup> are as provided above.

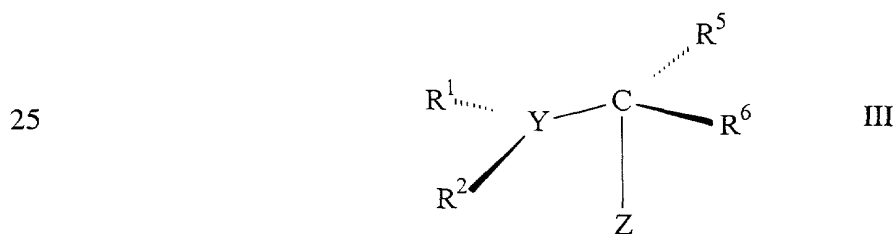
10 In another embodiment of the invention, the transition metal complex further comprises an activator. Generally, the activator converts the complex to a cationically active species. The catalysts are especially valuable for polymerizing olefins, such as ethylene, propylene, and/or other  $\alpha$ -olefins such as 1-butene or 1-hexene. Suitable activators are well known in the art. Preferred activators include

15 alumoxanes (e.g., methyl alumoxane (MAO), PMAO, ethyl alumoxane, diisobutyl alumoxane), alkylaluminum compounds (triethylaluminum, diethylaluminum chloride, trimethylaluminum), and the like. Such activators are generally used in an amount within the range of about 0.01 to about 100,000, preferably from about

1 to about 10,000, moles per mole of transition metal complex. Preferred activators also include acid salts that contain non-nucleophilic anions. These compounds generally consist of bulky ligands attached to boron or aluminum. Examples include lithium tetrakis(pentafluorophenyl) borate, lithium  
 5 tetrakis(pentafluorophenyl) aluminate, anilinium tetrakis(pentafluorophenyl) borate, and the like. These activators are generally used in an amount within the range of about 0.01 to about 1000, preferably from about 1 to about 10, moles per mole of transition metal complex. Suitable activators also include trialkyl or triarylboron compounds such as tris(pentafluorophenyl)boron, tris(pentabromophenyl) boron,  
 10 and the like. Other suitable activators are described, for example, in U.S. Pat. Nos. 5,756,611, 5,064,802, and 5,599,761, the teachings of which are incorporated herein by reference.

The catalysts are optionally used with an inorganic solid or organic polymer support. Suitable supports include silica, alumina, silica-aluminas,  
 15 magnesia, titania, clays, zeolites, or the like. The supports can be pretreated thermally or chemically to improve catalyst productivity or product properties. The catalysts can be deposited on the support in any desired manner. For instance, the catalyst can be dissolved in a solvent, combined with a support, and stripped. Alternatively, an incipient-wetness technique can be used. Moreover, the support  
 20 can simply be introduced into the reactor separately from the catalyst. The ligand can also be chemically tethered to the support through a suitable linking group.

In yet another embodiment of the present invention, a method for forming the metal complex having the ligand of the present invention is provided. The method comprises reacting a ligand precursor having the following structure:



with a metal compound with the structure:



where X is a halogen, to form metal complex II.

5 In another embodiment of the invention, an olefin polymerization process is provided. The process comprises polymerizing an olefin in the presence of a catalyst of the invention according to methods that are well known in the art. Suitable techniques include gas, high-pressure liquid, slurry, solution, or suspension-phase processes and combinations of these. Suitable olefins include  
10 ethylene, propylene, butenes, pentenes, hexenes, octenes, styrenes, 1,3-butadiene, norbornene, and the like. Preferred olefins are ethylene, propylene, and  $\alpha$ -olefins such as 1-butene, 1-hexene, and 1-octene.

The following examples illustrate the various embodiments of the present invention. All reactions are carried out in an inert, air-free atmosphere using  
15 vacuum line or dry box. All solvents are dry and deoxygenated. Those skilled in the art will recognize many variations that are within the spirit of the present invention and scope of the claims.

### Example 1

20 **Complex formed by reaction of pinacol [1--(trimethylstannyl)ethyl] boronate with cyclopentadienyl zirconium trichloride.**

A slurry of 2.63 (0.01moles) of cyclopentadienyl zirconium trichloride in 100 ml of toluene at dry ice temperature is combined with 3.25g (0.01 moles) of pinacol [1--(trimethylstannyl)ethyl]boronate, prepared according to D.J. Matteson et al, *Organometallics*, v.4, p. 1690 (1985). The mixture is gradually  
25 warmed up to room temperature and refluxed for 24 hours. The residue after evaporation of toluene is washed with cold hexane and used in polymerization experiments without further purification.

## Example 2

### **Complex formed by reaction of pinacol (1-lithioethyl)borate with cyclopentadienyl zirconium**

To a cold (-100°C) solution of pinacol (1-lithioethyl)borate in 100 ml  
5 of THF prepared according to reference 4 from 3.25g (0.01 moles) of pinacol [1-  
(trimethylstannyl)ethyl]boronate 0.01 moles of THF complex of cyclopentadienyl  
zirconium trichloride is slowly added. The mixture is gradually warmed up at room  
temperature and stirred for 24 hours. The residue after evaporation of THF is used  
for polymerization without further purification.

## Example 3

### **Preparation of a supported catalyst.**

To 2 ml of 4.1 M solution of polymethylalumoxane in toluene 0.005  
g of the complex formed in Example 1 is added and stirred for 1 hr at ambient  
temperature. The resulting solution is added slowly to stirred bed of dehydrated  
15 silica support to result in a free-flowing catalyst powder.

## Example 4

### **Polymerization of ethylene.**

About 0.25 g of the supported catalyst formed in Example 3 is added  
to a 1000 ml reactor charged with 500 ml of isobutane and 1 ml of 2M solution of  
20 triisobutylaluminum in heptane and ethylene is polymerized at 350 psi ethylene  
pressure at 70°C to produce high molecular weight polyethylene.

While embodiments of the invention have been illustrated and  
described, it is not intended that these embodiments illustrate and describe all  
possible forms of the invention. Rather, the words used in the specification are  
25 words of description rather than limitation, and it is understood that various changes  
may be made without departing from the spirit and scope of the invention.